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Camera-Based Automatic System for Tool Measurements and Recognition

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Abstract

In the last decades video capturing technology has become inexpensive, good quality and thus broadly used. Video cameras are currently one of the inexpensive sensors giving large amount of meaningful data. This paper focuses on the usage of an automated video-based system for turning tools base plane wear assessment. Paper presents algorithms and image processing routines required for successful implementation of such a system. Presented system consists of a USB camera with VGA resolution combined with software tools required to perform tool wear analysis. Picture acquisition and analysis software was developed using Visual Basic. Analyses can be conducted on selected regions of the image. Software is capable of image segmentation aimed at automated tool identification in the image as well as assessing geometrical parameters of the tools' cutting edge in the base plane. Program uses knowledge base for tools' wear identification. The presented method has been verified to show validity of the concept. The concept was found to be of practical importance and also convenient as a tool for teaching.

Keywords: picture analysis; optical measurements; turning tools; USB camera; tool wear.

1. Introduction

Measurement techniques based on image are currently widely used [1-3]. Its popularity is mostly associated with the development in image processing algorithms, constantly improving image quality with lowering prices of the

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digital cameras, and development in the computing power of current desktop and laptop computers. Analogue cameras which has been used in the past required digitization hardware to transfer image data to a computer. This obstacle has been alleviated with the modern digital cameras, which output is directly usable on PC. Digital cameras combined with software created a possibility to progress to new applications of image based sensing [4-8]. Applications include among picture recognition processes [5] also measurement devices [4,9]. Resolution and picture quality of even simple USB cameras allows for wide range of their applications. Mostly due to high data transmission rate and relatively low cost of even high definition cameras [10-12,15-17]. Image quality depends mostly on the sensor type used, its resolution, matrix size, and the quality of optics. Secondarily it also depends on the built in software image enhancement algorithms. Selection of the right zoom value enables to increase sensitivity of the device to details by expanding feature resolution to a value close to the matrix size resolution [5]. Picture enhancement algorithms allow to alleviate problems related to inexpensive plastic optics or noise related to image matrix cross-talk. Image-based measurements are applicable to many technological process including:

- tool wear [3-9],
- surface quality measurements [15,16],
- 1D [11], 2D [10,12,13, 15,16] and 3D [2] geometrical measurements,
- 3D surface or motion reconstruction using photogrammetric methods [2],
- counting objects or features [14].

Use of such techniques can be combined together with artificial intelligence, e.g. neural networks, for tool wear analysis [6].

This work presents image-based turning tools measurement system combined with knowledgebase tools recognition. The work has been done at Department of Production Engineering of University of Science and Technology in Bydgoszcz, Poland in cooperation with the Laboratory of Machine Design, Lappeenranta University of Technology, Lappeenranta, Finland.

Nomenclature

Pr	base plane of tool's geometry	
κ_{r1} and κ_{r2}	cutting side angle	[degree]
b	tool holder width	[mm]
A1, A2, B1, B2	points on tool's edge	
$x_{A1}, y_{A1}, x_{A2}, y_{A2}$	coordinates of edge points	[mm]
C	tip of the cutting edge	
f	tool's tip coordinate	[mm]
D1, D2	points on tool's holder	
$x_{D1}, y_{D1}, x_{D2}, y_{D2}$	coordinates of tool's holder	[mm]
p1, p2, p3	secant lines of tool control	
lr	real size of object	[mm]
ls	size object on screen	[mm]
$zoom_x$	magnification of the tool	
q, p, x_{eps}	calculated parameters	

2. Materials and methods

2.1. Principles of turning tool measurements

For the measurement of the geometry and dimensions of the turning tool, edges are imaged with a camera. In the measurement procedure it was assumed that the tool holder was perpendicular to the camera optical axis. Tool's cutting edges angles measurements depend on defining coordinates of lines p_1 and p_2 and their intersections with the cutting edge (Fig. 1). Having coordinates of points A1, B1 and A2, B2 it is possible to define tool's cutting angles

κ_{r1} and κ_{r2}. Width of tool's holder is a distance between intersection point on the line p_3 with holders body outline (Fig. 1, steps 5 and 6).

Identification of tools' angles has to be defined with respect to the surface P_r. Angles κ_{r1} and κ_{r2} can be computed then using the following equations:

$$\frac{y_{B1}-y_{A1}}{x_{B1}-x_{A1}} = tan(\kappa_{r1}) \tag{1}$$

$$\kappa_{r1} = arctan\left(\frac{y_{B1}-y_{A1}}{x_{B1}-x_{A1}}\right) \tag{2}$$

$$\kappa_{r2} = arctan\left(\frac{y_{B2}-y_{A2}}{x_{B2}-x_{A2}}\right) \tag{3}$$

Tool holder width b can be obtained using the following relationship:

$$b = (x_{D2} - x_{D1}) \cdot zoom_x \tag{4}$$

Tool's tip coordinate f can be evaluated using equation (8), where parameters: q, p, and x_{eps} are defined in equations (5), (6), and (7) respectively.

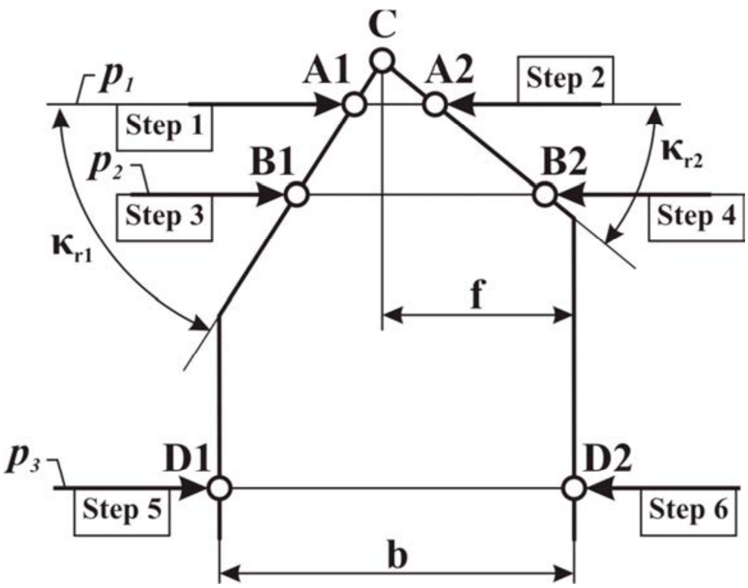

Fig. 1. Steps of edge measurement in the P_r plane

$$q = \frac{y_{B1}-y_{A1}}{x_{A1}-x_{B1}+1} \tag{5}$$

$$p = \frac{y_{B2}-y_{A2}}{x_{B2}-x_{A2}+1} \tag{6}$$

$$x_{eps} = \frac{q \cdot x_{A1}-y_{A1}+y_{B1}-p \cdot x_{A2}}{q-p} \tag{7}$$

$$f = x_f - x_{epx} \tag{8}$$

2.2. Measurement system

System uses a USB camera (CMOS VGA - 640x480 resolution) as an image acquisition device (see Fig. 2).

Fig. 2. Schematics of image-based cutting tool measurement system

Camera is connected to a computer that uses self-developed software in Visual Basic 6.0 for image acquisition and analysis. Calibration of camera makes it possible for video-optical measurements of linear dimensions on a flat surface. Value of calibration factor depends on the distance between work piece surface and the camera. The video-optical measurement accuracy depends on the camera's resolution and optical zoom factor [13]. Optical zoom allows magnify the object in the field of view the size close to the camera's sensor dimension. Digital magnification of the image allows for additional magnification.

Between the real size of the object *lr* and its image representation on screen *ls* a relationship is defined in equation (9).

$$ls / lr = zoom \tag{9}$$

Dimension *ls* increase with camera resolution and optical zoom. The accuracy of screen measurement is *ds* and depends on pixel size. The accuracy of video optical measurements of the real object *dr* is defined in equation (10).

$$dr = ds / zoom \tag{10}$$

This relation is illustrated at Fig. 3 in the example for *ds*=0.24 mm. Value of *dr* decrease with using micro scale (*zoom*>1) and strongly increase in macro scale.

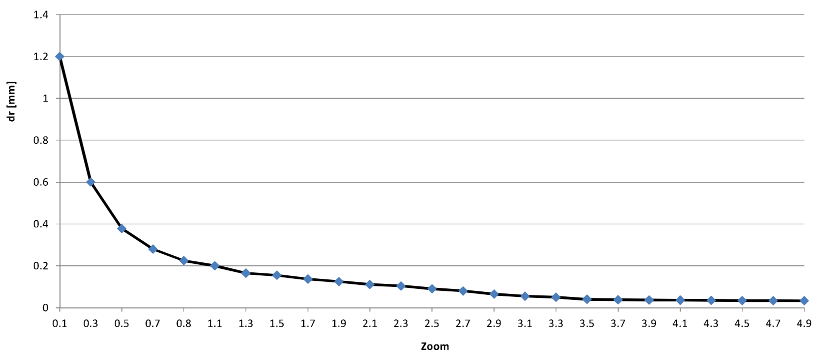

Fig. 3. Effect of zoom on measurement accuracy

Furthermore by analysis of edges brightness, image resolution can be up-sampled to allow for sub-pixelar features to be detected [2, 18]. Special photogrammetry methods like for instance bi-cubic scaling, together with a precisely calibrated camera can increase accuracy of the measurements up to 1/50 of a pixel [18]. Figure 4 shows a view of the test stand. The additional adjustable lamp enab8les convenient object lighting.

Fig. 4. View of setup

2.3. Software for image-based measurement of turning tools

Based on equations (1) to (8) a computer program *ToolMea* (using VB) was developed for cutting edge geometry measurements (see Fig. 5 for screenshot).

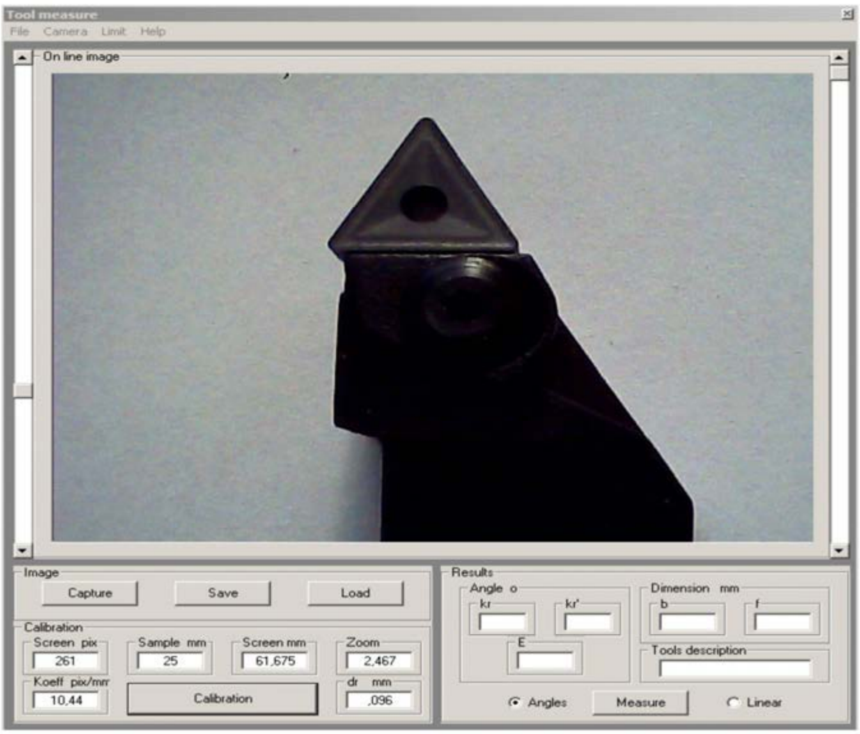

Fig. 5. Main window of *Tool Mea* software for cutting angle measurements

The software allows for image acquisition from a USB camera, and online image preview. Image is saved on demand when setting up of the cutting edge is done. In addition to camera image analysis software allows also to process saved images. In each case camera calibration data need to be supplied.

Image pixels colors are analyzed during the image segmentation stage followed by feature recognition procedure to find tool's edges. Intersection between lines are found based on comparison of measured object's color with background. Background color can be determined in the software and is used as constant for the whole image. Sliders at the edge of image area allow to set image measurement points. According to the measurement protocol, three secants are used to determine tool's angles (see Fig. 1). Two of the secants are used to determine location of the cutting edges and one to measure tool's holder width.

Before measurements are performed the system needs to be calibrated to determine pixel to mm conversion factor. Object with known dimensions can be used for that purpose as presented in Fig. 5. In this figure example is presented with the values obtained during camera calibration (sample size on the screen = 61.67 mm, *zoom* = 2.467, *dr* = 0.096 mm).

Tool identification is possible when cutting edge angles and linear parameters (tool holder's width) are determined. Parameter f is calculated in the software too. Measurement procedure implemented in the software is presented in Fig. 6.

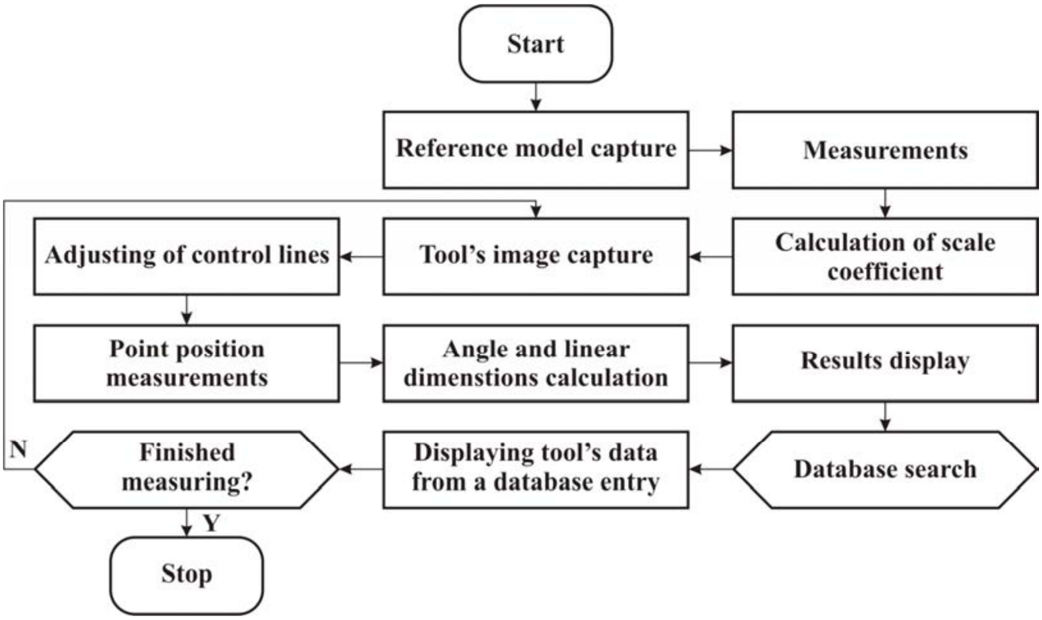

Fig. 6. Algorithm of tool measurement and recognition process

Results summary is presented in the results panel of the software. The software calculates tool's angles κ_{r1}, κ_{r2}, edge angle ϵ, holder's width b, and tip location f. Based on those parameters the software performs database search for tool data. Additional manufacturer's data are then presented on a side panel.

3. Results and discussion

The hardware-software solution presented in this article was used to test turning tool evaluation. A series of 10 measurements of a single edge with constant camera location and constant calibration was performed. In the test tool PTTNR 2525-16 (PAFANA Poland) with geometry (κ_{r1}=60°, κ_{r2}=60°, ε=60°, γ_o=-5°, λ_s=-6°) has been used. Each time changing tool's orientation and location in the camera's field of view. The results of this experiment are presented in Table 1. During all the trials software was capable of fail-free tool identification.

The results of the measurements show that a significant accuracy can be achieved despite the simplicity of the technique. Despite a small optical *zoom=2.467* obtained parameter *dr* was equal to 0.096 mm. Due to the inclination of the blades, the values of angles were determined to be κ_{r1} = 58.28º, κ_{r2}= 58.20º. The edge angle was computed to be ε = 63.51º, which was greater than the nominal value due to the abbreviation of the associated inclined blade. These values, however, by setting an appropriate margin for error, the width of the holder to b = 25.00 mm, and coordinate of the tip of the edge f = 22.51 mm (nominal value f = 22.00 mm) were sufficient for reliable identification of the tool.

Table 1. Cutting tool measurements results

No	κ_{r1}	κ_{r2}	ε	b	f
1	58,67	58,28	63,04	25,00	22,50
2	58,28	58,28	63,43	25,00	22,54
3	58,28	58,28	63,43	25,19	22,44
4	58,28	58,28	63,43	24,90	22,53
5	57,89	58,28	63,82	24,90	22,53
6	58,28	57,89	63,82	25,00	22,55
7	58,28	58,28	63,43	25,85	22,53
8	58,28	58,28	63,43	25,75	22,49
9	58,28	58,28	63,43	25,00	22,49
10	58,28	57,89	63,82	25,85	22,54
Average	58,28	58,20	63,51	25,24	22,51
δ	0,0184	0,0164	0,0247	0,0404	0,0034

4. Conclusions

Presented examples show possibilities of modern camera-based system tool measurements. Even VGA resolution camera was sufficient to conduct fail-free tool identification based on a database. Tools' geometrical parameter measurements were also possible to obtain with good accuracy in P_r plane of the tool.

Conducted tests allowed formulating the following conclusions:

- digital cameras with VGA resolution can be applied to geometrical measurements with linear dimensional accuracy +-0.1 mm, which is sufficient for turning tools identification purposes,
- presented experimental setup allows for repeatable measurements,
- presented test procedure allows for tool identification based on image features computed from the captured data and knowledgebase,
- camera-based measurement systems can be a viable alternative for manually performed tool measurements in production environment.

Further development of the presented applications in the use of cameras with higher resolution, automatic replication of measurements in the vicinity of the secant indicating the points of measurement will be conducted. Moreover, procedures should be improved for cutting edge geometry measurements at small values of auxiliary entering angle.

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